

Competition, Imitation, and Technical Change

Quality vs. Variety

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Abstract

Some researchers have documented that the path of development is remarkably related to the pattern of sectoral diversification. Others have highlighted the relation between productive specialization and economic progress. This paper explores the role of product market competition and intellectual property rights protection in the pattern of sectoral diversification. The paper confirms the insight of the innovation literature, that competition induces firms to specialize and upgrade the quality of existing goods. However, it reveals a new force, called

the imitation effect, through which competition biases technical change toward product diversification. The paper shows that if knowledge spillovers increase with imitation, or the degree of product substitution is high, weak protection of property rights encourages firms to create low-quality goods, thereby directing technical change toward diversification. The predictions are tested with data on Italian firms' innovation activity. They are found to be consistent with observed behavior.

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Competition, Imitation, and Technical Change: Quality vs. Variety

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1 Introduction

In a recent paper, Imbs and Wacziarg[32] find that the path of development is remarkably related to the pattern of sectoral diversification. Furthermore, Acemoglu and Zilibotti[2] provide a theory that links sectoral diversification and market incompleteness to capital accumulation and growth. Other contributions in this literature, including Gurley and Shaw[26] and Saint-Paul[44], highlight the relation between productive specialization and economic progress. This paper explores the role of product market competition and intellectual property rights protection on the pattern of sectoral specialization.

In doing so, the paper develops an endogenous growth model in which high-productive firms innovate and low-productive companies imitate. Innovating firms can perform two different types of innovations. They can improve the quality of existing products, or they can create new but on average low-quality goods. Imitating firms decide what kind of good to copy. The framework includes knowledge spillovers from the R&D activity, and a

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negative externality from past innovations, which makes the invention of new and better products progressively more difficult.

The model delivers four predictions. First, it confirms the insight of the innovation literature that competition induces firms to introduce vertically superior goods. However, it reveals a new force, through which competition biases technical change toward product diversification. We refer to this force as the imitation effect, and it appears as a result of the following process. On one hand, competition encourages firms to upgrade the quality of existing products because the marginal benefit of adding one extra unit of quality to an existing variety increases with the degree of product substitution. On the other hand, competition makes the leading-edge quality grow at a faster pace, which reduces the likelihood for high-quality products to be replaced by new goods. This effect increases the return from imitating leading varieties, and thereby shifts innovators' incentives from specialization toward diversification.

Second, the model supports the standard result that weak protection for intellectual property rights reduces R&D incentives. However, it shows that if knowledge spillovers increase with imitation, or the degree of product substitution is high, imitation has a larger negative impact on product specialization than on product diversification. In other words, imitation biases technological change toward the creation of low-quality goods. This result is novel, and highlights a relevant issue related to the role governments might play in fostering economic progress through strengthening intellectual property rights.

Third, the model shows that the increasing complexity to innovate in both dimensions introduces a complementarity between both types of innovations, which makes the simultaneous creation of new and better products more profitable than the development of each activity in isolation. As a result, quality and variety grow together. Finally, combining the first and the third predictions, the paper rationalizes why quality up-grading is an inverted U-shaped function of the degree of product market competition. To our knowledge, this is the first paper that provides microeconomic foundations to such relationship within a framework that allows firms to innovate in more than one dimension.

To assess empirically the predictions of the model and the mechanisms it proposes, the paper employs data on Italian firms' innovation activity during the periods 1998-2000 and 2001-2003. The data offer a particularly good ground to test the theory, as they provide detailed information about the types of innovations that firms decide to carry out. The theoretical findings are found to be robustly consistent with observed behavior.

Literature review

This paper relates to the literature on competition, imitation, and innovation. Standard theories such as the one provided by Schumpeter[45], Dasgupta and Stiglitz[19], Spence[49], Romer[43], Aghion and Howitt[5], Grossman and Helpman[25], and Vives[53] highlight a negative relationship between innovation and competition. Others such as Sutton[51], Shaked and Sutton[47], and Motta[39] suggest instead a positive association; while another group of papers, including Aghion, Harris, and Vickers[3], Aghion, Harris, Howitt and Vickers[4], Aghion, Bloom, Blundell, Griffith, and Howitt[6], claim a non-monotonic relationship.

The empirical evidence continues to be mixed. Some empirical works by Porter[41], Geroski[23], Baily and Gersbach[8], Nickell[40], Blundell, Griffith and Van Reenen[12], and Symeonidis[52] support the view that competitive pressures encourage innovation. Others such as Aghion, Bloom, Blundell, Griffith, and Howitt[6] show that the relation is inverted U-shaped.

Regarding the impact of imitation on innovation, the results are also quite diverse. Some contributions, including Helpman[28], Glass and Saggi[26], and Dinopoulos and Sergerstrom[19], remark the potential disadvantages of strong IPRs on innovation. Others, such as Lai[35] and Yang and Maskus[54], highlight, by contrast, that intellectual property rights protection (IPRs) foster innovation and technology diffusion. Interestingly, all the papers rely on the same assumption, that firms innovate exclusively in one dimension i.e., process-innovation, product-innovation, or quality-innovation. However, the literature has been silent about the role competition and imitation play to bias technical change. This paper comes to fill this gap.

The paper is structured as follows. Section 2 presents the model. Section 3 solves the equilibrium of the model. Section 4 presents the empirical results.

The last section concludes.

2 The Model

This section presents a model built on a combination of the love for variety approach of Spence[50] and Dixit and Stiglitz[20], and the Howitt[29] model of endogenous growth with vertical and horizontal innovations.¹ In this set up, the economy consists of two sectors, one in which firms produce a final good, and another sector in which firms create new and improved versions of the existing intermediate products.

2.1 Final Good Sector

Firms in this sector generate consumption goods and *R&D* services, under perfect competition using the same technology. The economy output is produced with a constant returns to scale production function. The inputs in the production process are labor and a continuum of intermediate products. Total output of the economy at time t is as follows:

$$Y_t = C_t + H_t + V_t, \quad (1)$$

where

$$Y_t = L_{yt}^{(1-\alpha)} \left[\int_0^{N_t} (q_{it} x_{it})^{\frac{(\sigma-1)}{\sigma}} di \right]^{\alpha \frac{\sigma}{(\sigma-1)}}. \quad (2)$$

C_t is consumption; H_t are horizontal *R&D* expenditures; V_t are vertical *R&D* expenditures; N_t is the number of intermediate products available in the economy; q_{it} is the quality of variety i ; x_{it} is the quantity of variety i ; $\sigma > 1$ is the elasticity of substitution between any two varieties of the intermediate good; and L_{yt} is labor.

A typical firm j that produces the final good maximizes its profits π_{jt} choosing L_{yjt} and x_{ijt} , where π_{jt} is given by the following expression:

¹Vertical innovations are related to the improvement of existing products while horizontal inventions are associated to the creation of new goods.

$$\pi_{jt} = L_{yjt}^{(1-\alpha)} \left[\int_0^{N_t} (q_{ijt} x_{ijt})^{\frac{(\sigma-1)}{\sigma}} di \right]^{\alpha \frac{\sigma}{(\sigma-1)}} - w_t L_{yjt} - \int_0^{N_t} p_{it} x_{ijt} di. \quad (3)$$

p_{it} stands for the price of intermediate input i , and w_t is the wage bill per worker. The solution to the profit maximization problem delivers the following demands for intermediate i and labor:

$$x_{it} = \frac{\alpha Y_t p_{it}^{-\sigma} q_{it}^{(\sigma-1)}}{\left[\int_0^{N_t} p_{it}^{(1-\sigma)} q_{it}^{(\sigma-1)} di \right]} = \frac{\alpha Y_t p_{it}^{-\sigma} q_{it}^{(\sigma-1)}}{P_t^{1-\sigma}}, \quad (4)$$

and

$$w_t = (1 - \alpha) L_{yt}^{-\alpha} \left[\int_0^{N_t} (q_{it} x_{it})^{\frac{(\sigma-1)}{\sigma}} di \right]^{\alpha \frac{\sigma}{(\sigma-1)}}. \quad (5)$$

2.2 Intermediate Good Sector

This sector is composed by two sets of firms, innovators and imitators, distinguished by an exogenous pattern of productivity to innovate. High productive firms are innovators while low productive companies are imitators. In the steady-state, the proportion of imitators relative to innovators is equal to m .²

2.2.1 Innovators

Innovators can engage into two different types of $R\&D$ activities, vertical and horizontal. When firms involve in the vertical activity, they do so with the goal of increasing the quality of an existing intermediate product. The new good embodies the highest quality of the market, Q_t i.e.

²We make this assumption because we are not interested in explaining the decisions to enter in the innovation or imitation activities. However, we are concerned with rationalizing the type of products that innovators and imitators decide to produce.

$Q_t \equiv \max \{q_{it} : i \in [0, N_t]\}$.³ And the innovator enters in Bertrand competition with the previous supplier of the product.

Each firm j that intends to innovate vertically in variety i faces a poisson probability equal to $\phi_{ijt}^v = \frac{v_{ijt}}{Q_t}$ of being successful, where v_{ijt} are the $R\&D$ expenditures that the firm devotes to the research activity. Division by Q_t captures the idea that as time goes by and better products are introduced, researchers' productivity falls because the innovation processes becomes more complex.⁴

As in Caballero and Jaffe[15], and Howitt[29], the leading-edge quality grows over time as a result of knowledge spillovers produced in the vertical $R\&D$ activity. The size of the spillovers is proportional to the aggregate flow of vertical innovations, $\phi_t^v N_t$, and the factor of proportionality is given by $\frac{\gamma}{N_t}$. Parameter γ captures the intensity of the imitation activity. Division by N_t reflects the idea that as a sector develops an increasing number of intermediate products, each vertical innovation has a smaller impact on the stock of public knowledge used by researchers. As a result, the leading-edge quality grows over time at the following rate, $g_t^v = \frac{\dot{Q}_t}{Q_t} = \frac{\gamma}{N_t} \phi_t^v N_t = \gamma \sum_j \phi_{ijt}^v$.

Firms also engage in the horizontal $R\&D$ activity with the purpose of expanding the set of intermediate products. The quality of the new good is random and picked from the existing distribution of quality. Each firm j that intends to innovate horizontally faces a poisson probability equal to $\phi_{jt}^h = \frac{h_{ijt}}{N_t}$ of being successful, where h_{ijt} are the $R\&D$ expenditures the firm devotes to the horizontal activity. Division by N_t captures the idea that as a sector develops an increasing number of intermediate goods the invention of new products becomes more difficult.

2.2.2 Imitators

Imitating firms decide what kind of good to copy. In doing so, they compare the reward of imitating a high-quality product versus that of copying a non-

³As in Grossman and Helpman[25], Aghion and Howitt[5], we assume that since the current leaders have less to gain from vertically innovating than other firms, they do not participate in vertical $R\&D$ races.

⁴This assumption guarantee a balanced growth path equilibrium. Furthermore, Jaffe and Hall[33] have provided some evidence of increasing innovation complexity.

leading good. This product is chosen randomly from the existing distribution of intermediate goods.⁵ The returns to imitation can be written as follows:

$$z^v(1 - \lambda)R_{it}^v, \quad (6)$$

and

$$z^h(1 - \lambda)E[R_{jt}^h]. \quad (7)$$

z^v and z^h are realizations of random variables associated with the likelihood of being successful in the imitation process. As copying a high-quality product is a more complex process than imitating a low-quality good, we assume variable $Z \equiv \frac{z^v}{z^h}$ is distributed uniformly over the interval $[0, 1]$. R_{it}^v is the reward of up-grading the quality of an existing product, and R_{jt}^h is that of creating a new good. If an innovator is imitated, he retains a proportion λ of the benefits of his invention, while the rest, $1 - \lambda$, is appropriated by the fraudulent firm.

3 Equilibrium

This section solves the equilibrium of the model. For such purpose, we first characterize the distribution of quality in the steady-state. Second, we determine the equilibrium behavior of imitators. Finally, we find the equilibrium decisions of innovators.

3.1 Distribution of Quality in the Steady-State

When imitators and innovators decide what kind of product to produce, they compare the expected rewards of manufacturing a low-quality product versus that of producing a high-quality good. The relevant variable in such decisions is the ratio of sales in each scenario. Using equation (4), this ratio can be written as follows:⁶

⁵Notice that there will be no two imitating firms targeting the same variety. As Bertrand competition will leave them with negative profits.

⁶For the moment, assume that the price of each type of product is the same. This will be demonstrated in the coming sections.

$$E \left[\left(\frac{q_{it}}{Q_t} \right)^{(\sigma-1)} \right]. \quad (8)$$

Expression (8) can be interpreted as the comparative disadvantage of the average firm relative to the leading company, adjusted by the degree of product market competition. To write expression (8) as a function of the parameters of the model; we need to characterize the distribution of quality in the steady-state. For such purpose, we employ two differential equations:

$$-\dot{\Phi}_t = \phi_t^v \Phi_t, \quad (9)$$

and

$$\frac{\dot{Q}_t}{Q_t} = \gamma \phi_t^v. \quad (10)$$

$\Phi_t \equiv P(q_{it} < Q_0)$ and Q_0 is the leading quality of period t_0 . Equation (9) says that after time t_0 , the rate at which vertical innovations cause the mass of products behind Q_0 to fall is, in the steady-state, equal to the overall flow of vertical innovations occurring in varieties currently behind Q_0 . There are Φ_t of such goods, and the Poisson arrival rate of vertical innovations in each of these products is equal to ϕ_t^v . Equation (10) shows that the leading quality grows over time as a result of knowledge spillovers in the vertical activity. The following proposition characterizes the distribution of quality in the steady-state.

Proposition 1 *The distribution of $a_{it} \equiv \frac{q_{it}}{Q_t}$ converges monotonically to the invariant distribution $\Pr = (a_{it} \leq a) = F(a) = a^{\frac{1}{\gamma}}$, with $0 < a \leq 1$.*

Corollary 1 $E \left[\left(\frac{q_{it}}{Q_t} \right)^{(\sigma-1)} \right] = \int_0^1 a_{it}^{(\sigma-1)} F'(a) da = \frac{1}{[\gamma\sigma + (\gamma-1)]}.$

The methodology employed to proof proposition 1 borrows from Sergerstrom[46], and it is presented in the Appendix. Corollary 1 shows

that imitation makes the knowledge spillovers to flow at a larger pace. As a result, the sale-gap between the average firm and the leading firm is an increasing function of imitation. This gap also depends positively on the degree of product market competition.

3.2 Imitators

Given equation (6) and (7), the probability of imitating a vertical innovator can be written as follows:

$$P = P[z^v(1 - \lambda)R_{it}^v \geq z^h(1 - \lambda)E[R_{jt}^h]] = 1 - \frac{E[R_{jt}^h]}{R_{it}^v}. \quad (11)$$

Inserting the result of Corollary 1 into equation (11) we obtain the following solution:

$$P = 1 - \frac{1}{[\gamma\sigma + (\gamma - 1)]}. \quad (12)$$

Equation (12) shows that imitation and competition increase the probability that imitators copy a high-quality product. Indeed, if $\gamma > 1.5$ or $\sigma > 2$, quality innovators are more exposed to imitation than variety inventors as $P > 0.5$.

3.3 Innovators

Entry in the innovation activity occurs until the marginal firm just breaks even. The free entry condition for quality-innovations is as follows:

$$[1 - P(\sigma, \gamma)m(1 - \lambda)]\frac{v_{ijt}}{Q_t}R_{it}^v = v_{ijt}. \quad (13)$$

The free entry condition for variety-innovations is:

$$[1 - (1 - P(\sigma, \gamma)(1 - \lambda)m)]\frac{h_{jt}}{N_t}E[R_{it}^h] = h_{jt}. \quad (14)$$

Since arbitrage can not occur in equilibrium, both $R\&D$ activities must yield identical rewards. Therefore, combining equations (13) and (14); we obtain the non-arbitrage condition, which can be written as follows:

$$\frac{Q_t}{N_t} = \frac{[1 - P(\sigma, \gamma)m(1 - \lambda)]}{[1 - (1 - P(\sigma, \gamma))(1 - \lambda)m]}[\gamma\sigma + (\gamma - 1)]. \quad (15)$$

Four implications can be obtained from equation (15).

Implication 1: Let $\gamma > 1.5$ or $\sigma > 2$. The larger the proportion of firms that receive a negative impact from imitation, m , the lower the quality-bias of technical change i.e.,

$$\frac{\partial \frac{Q_t}{N_t}}{\partial m} = -\frac{(1 - \lambda)(2P(\sigma, \gamma) - 1)[\gamma\sigma + (\gamma - 1)]}{[1 - (1 - P(\sigma, \gamma))(1 - \lambda)m]^2} < 0 \quad (16)$$

Implication 2: Competition affects the quality- bias of technical change through two different channels. A positive business-stealing effect, and a negative imitation effect i.e.,

$$\frac{\partial \frac{Q_t}{N_t}}{\partial \sigma} = \underbrace{\frac{-(1 - \lambda)[2mP(\sigma, \gamma) - 1][\gamma\sigma + \gamma - 1]}{[1 - (1 - P(\sigma, \gamma))m(1 - \lambda)]^2}}_{\text{imitation-effect} < 0} + \underbrace{\frac{[1 - P(\sigma, \gamma)m(1 - \lambda)]\gamma}{[1 - (1 - P(\sigma, \gamma))m(1 - \lambda)]}}_{\text{business-steal.-effect} > 0}. \quad (17)$$

The first effect is related to the shift of incentives that competition generates toward specialization. When competition is high, the entrance of new products in the market reduces incumbents' output by much more than in the case where goods are imperfect substitutes. As a result, innovators escape from competition by upgrading the quality of the existing intermediate products.

The second effect directs technological change in the opposite direction. And it is a result from the fact that, through the business-stealing effect,

competition increases knowledge spillovers and makes the leading-edge quality grow at a faster pace. Thereby encouraging imitators to copy high-quality goods.

Implication 3: The complexity to innovate in both dimensions introduces a complementarity between quality and variety. As a result, they grow together i.e.,

$$g_{Q_t} = g_{N_t}. \quad (18)$$

To understand how the complementarity between quality and variety emerges in our model, suppose that the economy is out of the equilibrium situation, and that the non-arbitrage condition is not satisfied, with the reward to horizontal investments exceeding that of vertical research. Under this scenario, *R&D* firms find optimal to innovate only in the horizontal dimension.

However, as time goes by, and new products are introduced, researchers' productivity falls because innovation becomes more complex. The probability of being successful in this process diminishes, and thereby horizontal innovations start to become less attractive. Firms continue investing in the horizontal direction until a point in time at which quality up-grading is equally rewardable. Since in equilibrium both types of innovations must deliver the same profits, quality and variety must grow together.

Related evidence of this result at the country-level has been documented by Broda and Weinstein[13]. The authors report that in 1988, the average number of varieties exported by a country to the U.S was 12,822. This number increases to 14,572 in 1990, and continues growing up to a value of 16,390 in 2001. At the same time, the average value of a variety exported to the U.S was 2.67 dollars in 1988, 2.72 dollars in 1990, and 4.30 dollars in 2001.

Implication 4: Let $\Omega \equiv \frac{[1-P(\sigma,\gamma)m(1-\lambda)]}{[1-(1-P(\sigma,\gamma)(1-\lambda)m)]}[\gamma\sigma + (\gamma - 1)]$, $\Omega' \equiv \frac{\partial\Omega}{\partial\sigma}$ and $\Omega'' \equiv \frac{\partial^2\Omega}{\partial^2\sigma}$. If $\Omega'N + \Omega\frac{\partial N}{\partial\sigma} > 0$ when $\sigma \rightarrow 1$, $\Omega'N + \Omega\frac{\partial N}{\partial\sigma} < 0$ for some $\sigma > 1$, and $\Omega''N + 2\Omega'\frac{\partial N}{\partial\sigma} + \Omega\frac{\partial^2 N}{\partial^2\sigma} < 0$, then quality up-grading is an inverted U-shaped function of σ .

This implication shows that we can decompose the effect of product market competition, σ , on quality up-grading, Q_t , into two different effects: a *substitution effect*, $\Omega'N$, and a *complementary effect*, $\Omega \frac{\partial N}{\partial \sigma}$. The first effect is related to the shift of incentives that changes in σ generate towards the introduction of vertically superior products. This effect is positive as long as the marginal gain from adding one extra unit of quality to an existing variety exceeds the expected marginal loss from imitation. The second effect emerges as a result of the complementarity between quality- and variety-innovations. And it affects quality up-grading in a contrary direction to that of the substitution effect.

Under the conditions described by implication 4, the model provides new theoretical foundations for the inverted U-shape relationship between vertical innovations and the degree of product market competition. It is interesting, that since 1970 until recently, there has been a lot of theoretical and empirical effort to try to figure out the shape of that relationship. However, it was not until 2004, when Aghion et al.[5] present their work, that the literature reaches a consensus. The authors rationalizes the inverted U-function with a step-by-step approach to technological progress, according to which incumbent innovators are not automatically leap-frogged by their rivals. In their model, competition may increase the incremental profit from innovating. However, it may also reduce innovation incentives for laggard firms. Our paper provides another explanation to such relationship based on the substitution and complementarity between different dimensions of the innovation process. We devote the following section to explore empirically the results.

4 Empirical Analysis

This section is organized as follows. First, we describe the data we employ to test the implications of the model. This involves the description of the proxies we construct, and a preliminary analysis of the data. Second, we present the empirical results together with some robustness checks.

4.1 Data

To test the model, we employ a survey conducted by the Central Bank of Italy, which gathers information about the innovative activity of Italian manufacturing firms during the periods 1998-2000 and 2001-2003. The data-set collects information for up to 4,660 and 3,452 firms during each period, respectively. A sub-sample of 1,634 companies has been followed since 1998 until 2003. The survey offers a particular good ground to test the theoretical findings, as it provides information on the types of innovations that firms decide to carry out. It also records business perceptions on the impact of imitation on enterprise performance.

4.1.1 Proxies

To test the model, we need to construct a proxy for the quality-bias of technical change. We also need a measure of the (quasi) elasticity of substitution between products, σ , and a proxy for the intensity of the imitation activity, m . The following paragraphs describe the proxies we construct for such purpose.

Quality-bias of technical change

To build a proxy for $\frac{Q_t}{N_t}$, we employ the theoretical assumption according to which the leading-edge quality grows over time as a result of knowledge spillovers in the vertical activity, which are a function of the number of firms that up-grade the quality of the existing products. Thus, our proxy is defined as the ratio between the number of firms that in a sector innovate to improve a good, relative to those that innovate to create new varieties. The survey gathers information about the size of each innovation: low, medium, and high. However, we restrict our analysis to high inventions, because they are the most correlated to R&D expenditures. We calculate our measure of the quality bias of technology for each 3-digit ATECO-91 sectors, and we focus on sectors that have more than 5 firms. We do so, to avoid having to employ the Cox transformation for sectors with no innovation, which is problematic as it delivers outlier values.

(Quasi) Elasticity of Substitution

To measure σ we employ the estimations and the sectoral classification proposed by Broda and Weinstein[13]. The authors extend the seminal work by Feenstra[21], and use data on U.S imports during the period 1990-2001 to estimate the elasticity of substitution between two products under a monopolistic competitive framework. They obtain estimations of such parameter for each 3-digit SITC (Rev.3) sectors, and they classify sectors in three categories: low- σ , medium- σ , and high- σ . Low- σ sectors are below the 33rd percentile in the distribution of the estimated σ . Medium- σ sectors are between the 33rd percentile and the 66th percentile. High- σ sectors are above the 66th percentile.

Imitation

To measure m we employ information about the impact of imitation on innovators' performance. The survey allows firms to classify such impact as follows: strongly significant, significant, or irrelevant. We define m as the proportion of firms that in a particular sector receive a strongly significant negative impact on sales due to imitation.

4.1.2 Data analysis

Before turning to the estimations, we look to the data and we analyze if there is preliminary evidence in support of our model. Because Proposition 1 and Corollary 1 are crucial to derive our results, we start the analysis exploring them. Recall that Corollary 1 shows that in equilibrium the following condition is satisfied:

$$E \left[\left(\frac{q_{it}}{Q_t} \right)^{(\sigma-1)} \right] = \int_0^1 a_{it}^{(\sigma-1)} F'(a) da = \frac{1}{[\gamma\sigma + (\gamma - 1)]}. \quad (19)$$

Figure 1 shows the relationship the data describe. In the y-axis we measure a proxy for the left hand side of equation (19), which is defined as the average of the ratio of the sales of any firm to that of the leading supplier, adjusted by the power of $\sigma-1$. In the x-axis we measure the right hand side, assuming $\gamma = 1$. The line represents the pattern we should observe according to the theory. The scatter plot shows the relationship the data describe. Interestingly, both graphs display similar patterns.

[Insert Figure 1 about here]

In addition, we examine if there is evidence supporting other results. Table 1 presents summary statistics of the main variables, and Table 2 shows their averages across sectoral categories with low- σ , medium- σ , and high- σ .

[Insert Tables 1 and 2 about here]

Table 2 shows that the mean of the quality-bias of technical change increases with the degree of product market competition. This measure is equal to 2.439, 3.755, and 3.961, for low- σ , medium- σ , and high- σ sectors, respectively. The table also reports that the proportion of firms that receive a negative impact from imitation is larger in high- σ sectors than in medium- σ ones. Finally, we look to the growth rates of quality and variety innovations at sectoral level and we find that their correlation is positive, equal to 0.343, and statistically significant at 1% level. This is consistent with our finding of complementarities. Overall, the evidence points to support the theoretical findings. However, we should explore these issues more formally. We devote the following section to this purpose.

4.2 Empirical Results

This section presents a set of different tests we perform to assess the empirical validity of our theory. First, we analyze whether competition and imitation bias technical change towards quality or variety. Second, we provide evidence of the channel through which imitation encourages firms to create new but on average low quality goods. Third, we test the existence of complementarities between quality- and variety-innovations.

4.2.1 Competition, imitation and technical bias towards quality

To analyze how competition and imitation bias technical change towards quality, we employ equation (15), and we assume $\gamma_0 = 1$. This allows us to separate the business-stealing effect from the competition effect. The resulting expression is as follows:

$$\frac{Q}{N} = \frac{[[1 - m(1 - \lambda)]\sigma + 1]}{[(\sigma - 1)m(1 - \lambda)]}\sigma. \quad (20)$$

Then, we apply logarithm to both sides of equation (20) to disentangle one effect from the other. The resulting expression is as follows:

$$\ln \frac{Q}{N} = \underbrace{\ln[(1 - m(1 - \lambda)\sigma + 1)] - \ln[(\sigma - 1)m(1 - \lambda)]}_{imit-effect} + \underbrace{\ln \sigma}_{bus.steal.-effect}. \quad (21)$$

We proxy the imitation effect with $\ln(1 + m\sigma)$.⁷ Our estimating equation becomes as follows:

$$\ln \frac{Q_s}{N_s} = \beta_0 + \beta_1 \ln(1 + m_s \sigma_s) + \beta_2 \ln \sigma_s + \beta_3 \ln(1 + m_s) + \beta_4 Z_s + \mu_s. \quad (22)$$

Z_s is a vector of control variables at sectoral level. It includes variables such as the logarithm of workers, the logarithm of the volume of exports, capital intensity of the sector, and skill intensity of the sector.⁸ We include these variables to be sure that the coefficients of interest are capturing the effect we want to measure and not the impact of one of these variables if they are omitted from the model. In particular, capital and skill intensive sectors may have an advantage in the production of high quality products. Sectors with large volume of exports frequently supply better goods to appeal to the standards of international markets, and large sectors innovate strongly in both dimensions.

Since data on imitation are only available for the period 2001-2003, our results correspond to that period. According to the theory, coefficient β_1 is expected to be negative, and coefficient β_2 is expected to be positive. Table 3 presents the estimation results.

[Insert Table 3 about here]

⁷We add 1 to the logarithm of $m\sigma$ to avoid missing observations for which $m = 0$.

⁸We employ the Bartlesman and Gray[9] data set to construct the capital and skill intensity indices.

Columns (2), (4), (6), and (8) display the regression outcomes when the dependent variable is as in equation (22). Columns (3), (5), (7), and (9) show the estimation outputs when we redefine it, by adding cost reducing innovations to quality ones.⁹ In this case, the empirical evidence shows the impact of competition and innovation on the *vertical* bias of technical change. Columns (2)-(5) present the regression outputs for specifications without the constant term. The other columns report the estimation results for specifications with constant. Columns (2), (3), (6), and (7) display the estimation outputs when we test the σ -competition effect with the estimated σ from Broda and Weinstein[13]. The other columns report the results for the cases where we employ the Broda and Weinstein[13] sectoral classification.

The results presented in column (2) provide evidence in support of the theory. There is a positive σ -competition effect and a negative σ -imitation effect. A 10% change in σ causes, through the first effect, a 11.77% change in the quality-bias of technical change. The same variation generates on the average sector, through the second effect, a -9.93% change on the quality bias of technical bias. Both effects are statistically significant at 1% level.

Imitation affects the quality-variety ratio through two different channels. The first one corresponds to the channel we describe in the theoretical model, which impacts negatively on firms' incentives to provide high-quality products. A 10% increment in the propensity to imitate delivers a -9.93% change on the quality bias of the average sector. The second channel may be related to the effect of knowledge spillovers, γ , which encourage firms to up-grade the quality of existing products. A 10% change in m causes, through this way, a 34% increment on the quality-bias of technical change. However, this effect is not robust to other specifications.

According to column (2) capital intensive and large exporter sectors bias the technical change towards quality innovations. A 10% change in the volume of exports generates a 0.8% change in the quality-bias of technical change. The results displayed in column (3) quite resemble those of column (2), both in magnitude and statistical sense. Column (4) shows that the sign and significance of the coefficients of interest are the same as that

⁹It is straightforward to show that our model is isomorphic to both types of research activities.

in column (2). A change from the category of low- σ sectors to medium- σ sectors increases discretely the innovation composition of quality relative to variety in 1.849 points. Such increment is equal to 2.71 points if we compare low- σ sectors with high- σ ones. These results are robust to redefinitions of the dependent variable, and all the empirical findings are consistent across specifications.

4.2.2 Potential sources of empirical concern

Three potential sources of concern regarding the estimation of equation (22) are the following: the existence of endogenous explanatory variables, the lack of control for unobserved sectoral characteristics, and the reverse causality problem. This section explains the problems these drawbacks can deliver and the way we address them.

Endogenous regressors

It may be argued that the intensity of the imitation activity is an endogenous variable, or that the volume of exports, or the size of a sector depend on firms' decisions. If these arguments are valid, the covariances between the explanatory variables and the error term are different from zero, and the estimated coefficients are inconsistent. The method of instrumental variables (IV) provides a general solution to this problem. Employing the IV approach requires to find, for each endogenous regressor, an observable variable which satisfies two conditions. The first condition requires that the variable be not correlated with the error term. The second requirement demands that the coefficient of the instrumental variable in the linear projection of the endogenous variable onto all the exogenous regressors be statistically different from zero. This condition means that the instrument is correlated with the endogenous variable once the other exogenous variables have been netted out.

Finding an instrument for the intensity of the imitation activity at sectoral level is not a simple task as most of the measures of intellectual property rights protection are only available at country level. To exploit these data, we combine information on export destinations at firm-level with measures of intellectual property rights protection from Ginarte and Park[24]. There

are 8 broad destinations to which firms can export: EU (EUR) (countries included before 2001); Russia and other European countries (ROE); Africa (AFR); Middle East and Asia (excluding China)(MEA); China (CHI); U.S, Canada and Mexico (UCM); Center and South America (CSA), and Australia and Oceania (AUO). For each firm, we construct an index of patent protection, which is defined as a weighted average of its regional-trading partners' IPRs, where the weights are the shares of exports on total sales. We then define the average of these index across firms as our instrumental variable. We instrument exports and size with their lagged values.

Table 4 shows the t-statistics of the null hypothesis that the second condition for an instrumental variable is not satisfied. The test is rejected for the three variables. The last row reports the p-values of the exogeneity tests. These tests are rejected for imitation and exports.

[Insert Table 4 about here]

Given the existence of endogenous variables, we can not rely on the results of Table 3 to assess empirically the validity of our theory. Thereby, to solve this problem, we use the IV approach, and we re-estimate equation (22) employing the instruments. Table 5 presents the estimation outputs. The econometric specification of each column corresponds to the same column in Table 3.

[Insert Table 5 about here]

Interestingly, all the results are in line with the theory. According to column (2), a 10% change in σ generates, through the competition effect, a 9.68% change in the quality-bias of technical change. Such variation causes, through the imitation effect, a -2.55% reduction in the bias of technical change. This effect is also equivalent to an increment of 10% in the degree of imitation. The fact that the new coefficient for the instrumented IPRs-variable is negative and statistically significant at 1% level highlights the importance of complementary IPRs-policies, among trading partners, to promote the creation of high quality products. The most notorious differences between Tables 3 and 5 are related to the significance of other variables such as capital intensity,

size, and volume of exports. The positive impact of capital intensity is not any more robust to modifications in the econometric specification. The same occurs with the volume of exports. In the new regressions, size appears to have a significant and negative impact on the bias of technology, while the volume of exports becomes statistically insignificant.

Unobserved sectoral characteristics

Having solved the endogeneity problem, we now move to analyze how the lack of control for unobserved sectoral characteristics affects our results. If an omitted characteristic is correlated with a regressor, we have inconsistency problems. If the unobserved feature is uncorrelated with any explanatory variable, but it affects systematically the dependent one, we have bias problems. One possibility to solve the inconsistency problem is to find instruments for the regressors correlated with the unobservable features, and to employ the instrumental variable approach. As we have done this before, we discard inconsistency as a problem. A way to solve the bias problem consists in controlling for observable characteristics correlated with the unobservable ones. Typical controls at sectoral level include: capital intensity, skill intensity, size, and exports. As we have done this before, we rule out bias in the estimated coefficients as a problem.

Reverse causality

The last source of concern regarding the estimation of equation (22) is the reverse causality problem. It may be argued that rather than estimating the effect of imitation on the relative supply of high and low quality products, we may be estimating the reverse effect. There are two reasons to invalidate this argument. First, assume the statement is true. If quality up-grading enhances imitation, then we would expect coefficients β_1 and β_3 to be positive and statistically significant. However, this is not the case. Second, instrumenting m_s with policy variables rules out the reverse causality possibility, as these they are exogenous regressors.

4.2.3 Robustness checks

Having discussed about some sources of empirical concern, we now move to conduct two robustness checks. The first one consists in testing the

σ -competition effect using the Rauch[42] classification. This classification groups sectors in three categories: goods traded in organized exchange, reference-priced products, and differentiated goods.¹⁰ The second robustness check consists in employing the ratio of $R\&D$ expenditures in quality-innovations to that in variety-innovations as the dependent variable. Because the survey does not provide information about the way firms splits total $R\&D$ expenditures across the two dimensions of the innovation process, with the exception of cases where firms innovate in one dimension, we assume that if a firm conducts quality- and variety-innovations, it spends the same amount of money in each activity. Table 6 presents the estimation results corresponding to these robustness exercises.

[Insert Table 6 about here]

Column (2) shows estimation outputs from the first robustness check. Column (3) presents the results from the second one. The first column shows evidence of a positive σ -competition effect. A change from the differentiated to the reference-priced category increases discretely the quality bias of technology in $e^{0.365}$ points. The coefficient of the σ -imitation effect is negative but insignificant, while that of imitation is negative but significant at 1% level. Finally, column (3) shows that the results are robust to the use of other dependent variables. All the estimated coefficients have signs in line with the theory, and they are statistically significant at 1% level.

Now, we move to test the channel through which imitation biases the technical change. This is presented in the following section.

4.2.4 Do imitators copy quality- or variety-innovations?

We have shown in previous sections, that imitation reduces firms' incentives to innovate in both dimensions, but if $1.5 < \gamma$ and/or $2 < \sigma$, it has a larger impact on quality up-grading. To test this prediction, we estimate the following probit model:

¹⁰The degree of product market competition decreases from the first to the third category.

$$IMIT_{jir}^* = \gamma_0 + \gamma_1 IQ_j + \gamma_2 IV_j + \gamma_3 IX_j + \gamma_4 Prod_j + \gamma_5 LnSize_j + \quad (23)$$

$$\gamma_i + \gamma_r + \mu_{jir}$$

$$IMIT_{jir} = 1[IMIT_{jir}^* > 0], \quad (24)$$

where the dependent variable is a dichotomous one, which takes value 1 if firm j from industry i and region r has received a significant negative impact from imitation and 0 otherwise. Variables IQ_j , IV_j , IX_j are dummy variables that take value 1 if firm j is a quality innovator, a variety innovator or an exporter, respectively, and 0 otherwise. Variable $Prod_j$ stands for firm j 's productivity and $LnSize_j$ stands for the logarithm of workers. Parameters γ_i and γ_r capture industry and regional effects, and μ_{jir} stands for the error term, which is assumed to be normally distributed with zero mean and variance equal to 1. Table 7 presents the estimation outputs.

[Insert Table 7 about here]

Column (1) reports the marginal effect of the explanatory variables on the dependent one.¹¹ The results provide evidence in line with the theory. A switch from the category of no innovator to the category of quality-inventor increases discretely the probability of imitation by 5.8% points, while a change from the category of no inventor to that of variety-innovator raises the imitation probability by 2.8% points. The first effect is significant at 1% level, while the second one is significant only at 10% percent. Finally, productive firms are also more likely to receive a negative impact from imitation. A 10% increment in the productivity of the average firm increases the probability that its product be copied by $2.44e^{-9}$ points. This effect is significant at 10% level. Small firms have also a larger probability of being imitated than big ones.

¹¹The effects are estimated for the average firm.

A potential source of concern regarding the estimation results of column (1) relies on the endogeneity of some explanatory variables such as the quality-, variety-innovator, and exporter conditions. As we explain before, this problem can deliver inconsistent coefficients. To address this drawback, we instrument the endogenous regressors with their lagged values. Table 8 displays the instrumental variable tests. Row (2) shows the t-statistics of the null hypothesis that each instrument is not significantly different from zero in the linear regression of the endogenous variable onto all the explanatory ones.

[Insert Table 8 about here]

The test is rejected for the three variables. The row at the bottom of the table reports the p-value corresponding to the Wald test of joint exogeneity. Because $0.05 < p$, the hypothesis can not be rejected, and the results displayed in Table 7 column (1) constitute robust evidence in support of our theory.

Having tested most of the implications of our model, we move to perform the last test. This is presented in the following section.

4.2.5 Do quality and variety complement each other?

In this section we test the existence of complementarities between quality and variety innovations. Recall that in our model, this complementarity emerges as a result of the increasing complexity to innovate, which makes both types of innovations to grow together.

To explore empirically this issue, we first look to the data and we analyze the correlation between the growth rate of quality and variety at sectoral level. We find that this correlation is positive, equal to 0.343, and statistically significant at 1% level, which provides preliminary evidence supporting our theory. Next, we test indirectly the model, by exploring the existence of complementarities between quality and variety at firm level. To do so, we employ the approach proposed and implemented by Cassiman and Veugelers[16], which consists in testing Milgrom and Robert's[38] definition of complementarity between two activities. According to the authors, two

activities complement themselves if adding one activity while the other is already performed has a higher incremental effect on a firm's performance than adding the activities in isolation. If this complementarity is observed, then we can infer that both types of innovations must grow together.

To perform the test, we regress a measure of innovation performance, the percentage of sales attributable to *R&D* expenditures, on exclusive combinations of the innovation activity, which is assumed to be of two types: quality- and variety-innovations. By restricting the performance measure to innovation returns only, rather than overall firm's performance, we address the problem of having to control for other sources of firm heterogeneity, which may influence the overall firm's profits. The resulting estimation equation is as follows:

$$\pi_{jt} = \gamma_{00} + \gamma_{11}IQ_{jt}IV_{jt} + \gamma_{10}IQ_{jt}(1 - IV_{jt}) + \gamma_{01}IV_{jt}(1 - IQ_{jt}) + \quad (25)$$

$$\gamma_t + \gamma_z Z_{jt} + \epsilon_{jt},$$

where IQ_{jt} and IV_{jt} are dichotomous variables that take value 1 if firm j in period t is a quality and variety innovator, respectively, and 0 otherwise. Z_{jt} is a vector of control variables that includes the exporter condition, the logarithm of workers, and the *R&D* intensity of the firm. Parameters γ_{00} and γ_t capture fixed- and time-effects, respectively. Table 9 presents the estimation results.

[Insert Table 9 about here]

Given the results of Table 9, we test the null hypothesis of no complementarities, $\gamma_{11} - \gamma_{10} = \gamma_{01} - \gamma_{00}$, against the alternative that performing both activities jointly has a larger incremental effect on firms' performance than conducting them separately, $\gamma_{11} - \gamma_{10} > \gamma_{01} - \gamma_{00}$. We obtain a p-value of 0.0347, which means that we reject the null hypothesis, and we provide evidence in support of our theory.

5 Conclusion

This paper investigates the role of product market competition and intellectual property rights protection in biasing the technological change toward specialization or diversification. The paper is suggestive of the role the government might play in order to foster economic progress: while the degree of product market competition and IPRs have been treated as exogenous in the analysis, they can be affected by government policies. If sectoral concentration and specialization are positively linked to development, policies that strengthen the degree of IPRs and/or that internalize the social returns of innovating vertically, can help to promote economic growth. If instead, diversification is positively related to development, policies that restrict the degree of product market competition, such as price ceilings, can foster economic progress.

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6 Appendix I

6.1 Proof of Lemma 1

To proof Lemma 1, we follow Sergerstrom[46]. Let $G(., t)$ denote the cumulative distribution of absolute quality q_{it} at time- t . Pick any $q > 0$ that was the leading-edge quality at some time $t_0 \geq 0$, and define $\Phi(t) \equiv G(Q, t)$. Then $\Phi(t_0) = 1$ since no variety can have a quality larger than the leading-edge at time t_0 , which by construction is Q .

Then, notice that in the steady state, the following condition must hold, $\dot{\Phi}(t) + \phi_t^v \Phi(t) = 0$ holds for all $t \geq t_0$. To understand this differential equation, note that since horizontal innovations represent random draws from the distribution of quality, they do not change the distribution of quality, and thus they can be ignored when characterizing the time path of Φ . Next note that after time t_0 , the rate at which vertical innovations cause the mass of varieties behind Q to fall is the overall flow of vertical innovations occurring in varieties currently behind q . There are $\Phi(t)$ of such varieties and the Poisson arrival rate of vertical innovations in each of these varieties is ϕ_t^v . Taking into account the initial value condition $\Phi(t_0) = 1$, the unique solution to the first order linear differential equation is $\Phi(t) = e^{-\int_{t_0}^t \phi_s^v ds}$ for all $t \geq t_0$.

The expression for the growth rate ($g_Q = \phi_t^v$) also represents another differential equation, which given the initial condition $Q_{t_0} = Q$, has a unique solution $Q_t = Q e^{\int_{t_0}^t \phi_s^v ds}$. Now, define $a \equiv \frac{Q}{Q_t}$. Then, using the solutions to the two differential equations it follows that $\Phi(t) \equiv P(q_{it} < Q) = P(\frac{q_{it}}{Q_t} < \frac{Q}{Q_t}) = \frac{Q}{Q_t}$ for all $Q \geq Q_0$, which can be alternatively expressed as $P(a_{it} \leq a) = F(a) \equiv a$ for all $a \geq \frac{Q_0}{Q_t}$. As t converges to $+\infty$, $\frac{Q_0}{Q_t}$ converges to zero. Thus, the distribution of relative quality converges monotonically over time to the invariant distribution $F(.)$.